Experimental investigations of interplay between single particle and collective excitations in A~40 nuclei

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Spectroscopic study of upper sd shell nuclei furnishes salient information about different interesting phenomenon like collective excitations, α-cluster, etc. These nuclei generally exhibit single particle excitations and large basis shell model (LBSM) calculation has successfully explained the excitation spectra of these nuclei [1]. Recent developments of the detection system made it possible to study these nuclei at higher angular momentum and excitation energy. As a result, apart from single particle excitations, collective excitations in term of deformed or superdeformed (SD) bands have been observed at higher excitation energy in a few *sd* shell nuclei viz., ^{36}Ar [2], ^{40}Ca [3] and odd-even ^{35}Cl [4] and explained them successfully by shell model calculations. Knowledge of the cluster configuration is also important since it has a great connection with the nuclear molecules [5], highly deformed rotational bands [2, 3], etc. Presence of α-cluster has already been established in a few nuclei in this mass region [1].Therefore, this A ≈ 40 region gives us an unique opportunity to investigate the interplay between single particle and collective mode of excitations both experimentally as well as theoretically using large basis shell model calculations.

In this work, an extensive study of high spin structure of ^{37}Ar, populated through $^{27}Al(^{12}C, np)^{37}Ar$ fusion evaporation reaction at E_{lab}=40 MeV at Tata Institute of Fundamental Research (TIFR), Mumbai, has been carried out. A multi-detector array (INGA setup) [6], comprising of 15 Compton suppressed clovers mounted at six different angles were used to detect the gamma rays. The excitation spectra have been extended up to 10.5 MeV by adding 8 new levels and 18 new gamma transitions (Fig. 1). The spins and parities of most of the levels have been assigned or modified or confirmed from R_{DCO} and linear polarisation measurements. For a few weak transitions, R_{ADO} measurements have been carried out to assign their dipole or quadrupole nature. Multipole mixing ratios (δ) of a few transitions have been evaluated using the code ANGCOR [7] and compared with the earlier measurements wherever available. We have identified a few levels at higher excitation energy whose level lifetimes are expected to be smaller than 430 fs, the estimated stopping time for ^{37}Ar in ^{197}Au backing. Among them, we have measured the lifetimes of two levels using lineshape analysis. B(E2) values calculated from the measured lifetimes and the corresponding β_2 values

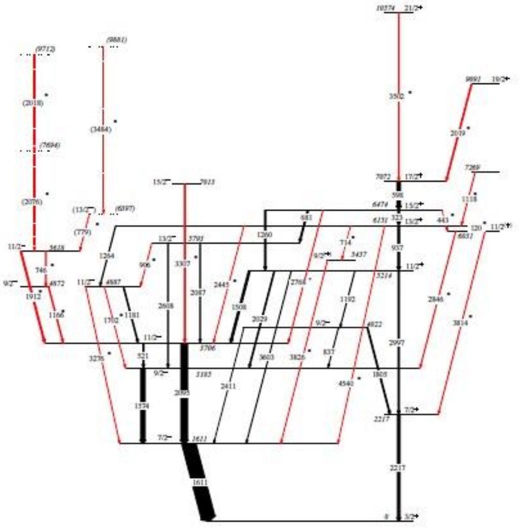

Figure 1: Level scheme of ^{37}Ar. Energy levels are given in keV. Width of the lines indicates their relative intensity. New γ transitions (red) are marked by asterisks. Tentative assignments areindicated by the dashed line.

confirm the presence of collectivity at higher excitation energy. Large basis shell model (LBSM) calculation has been performed using the code OXBASH [8] to obtain a detailed knowledge about the microscopic features of ^{37}Ar. The experimentally observed negative parity and high spin positive parity states of ^{37}Ar were reproduced by involving the neighbouring *pf* orbitals. A simple two-level mixing calculation has been performed to derive the amount of 0p-0h and 2p-2h configuration mixing for a few mid lying yrast positive parity states. The negative parity and high spin positive parity states exhibit substantial configuration mixing in terms of particle partitions, which gives an indication of the presence of collective excitations at higher excitation energy in ^{37}Ar. Experimental transition strengths for most of the transitions have been compared with the calculated values. The lifetimes of 4 new levels have also been calculated from shell model calculations and compared with the experimental observations.

A comprehensive theoretical study has been carried out in search of α-cluster structure at lower excitation energy of ^{34}S, a upper *sd* shell nucleus. In order to understand the structural properties of a light mass nucleus, knowledge about the cluster configuration is important since it has a great connection with the nuclear molecules, highly deformed rotational bands, etc. Cluster configuration has been interpreted in several *sd* shell nuclei using conventional anti-symmetrised molecular dynamics (AMD) [9], orthogonality condition model (OCM) [10, 11], generator coordinate method (GCM) [9], etc. In the case of ^{34}S, cluster configuration has been investigated through shell model calculations. In ^{34}S, nucleon transfer spectroscopic factors have been estimated by employing large basis shell model (LBSM) to infer the α-cluster configuration in the observed parity doublet states. ^{34}S stands one (two) proton away from ^{35}Cl (^{36}Ar). α-cluster structure has already been observed in superdeformed (SD) bands of ^{35}Cl (^{36}Ar). Therefore, LBSM calculation within the full sdpf model space have been performed to investigate the cluster properties at lower excitation energy in ^{34}S by correlating the states of interests in ^{34}S with the superdeformed states of ^{35}Cl and ^{36}Ar. Spectroscopic factors for states of interest of ^{34}S have been evaluated by coupling one (two) proton hole to the pf shell of the parity doublet states in ^{35}Cl (^{36}Ar). The obtained results infer that the states of interest in ^{34}S comprise of large spectroscopic factors corresponding to the core angular momentum SD states. Strong intra-band E2 transitions, strong decay out inter-band E1 transitions and significant spectroscopic factors indicate the presence of cluster configuration below 12 MeV in ^{34}S. From particle threshold energy calculations, it has been confirmed that the states of interest in ^{34}S configured with ^{30}Si+α cluster structure.

References

[1] http://www.nndc.bnl.gov.

[2] C. E. Sevenson *et al.*, Phys. Rev. Lett. **85**, 2693 (2000); C. E. Sevenson *et al.*, Phys. Rev. C **63**, 061301(R) (2001).

[3] E. Ideguchi *et al.*, Phys. Rev. Lett. **87**, 222501 (2001); C. J. Chiara *et al.*, Phys. Rev. C **67**, 041303 (R) (2003).

[4] Abhijit Bisoi *et al.*, Phys. Rev. C **88**, 034303 (2013).

[5] W. von Oertzen, Eur. Phys. J. A **11**, 403 (2001).

[6] R. Palit *et al.*, Nucl. Instrum. Methods A **680**, 90 (2012).

[7] E. S. Macias, W. D. Ruhter, D. C. Camp, R. G. Lanier, Comput. Phys. Commun. **11**,75 (1976).

[8] B. A. Brown, A. Etchegoyen, W. D. M. Rae, N. S. Godwin, MSU-NSCL Report No. 524, 1985.

[9] Y. Kanada-En'yo and M. Kimura, Phys. Rev. C **72**, 064322 (2005).

[10] T. Sakuda and S. Ohkubo, Phys. Rev.C **49**, 149 (1994).

[11] T. Sakuda and S. Ohkubo, Nucl. Phys. A 744, **77** (2004); T. Sakuda and S. Ohkubo *ibid* **748**, 699 (2005).